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Project Title: Quantification of the Individual Characteristics of the Human Dentition

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Abstract

This project initiated the development of a dataset which defines the frequency that a given set of dental characteristics occurs in the general population. The significance is that with the analysis of sufficient additional samples, a database could be produced from which the human dentition can be virtually individualized in a manner similar to that of mitochondrial DNA (mtDNA).

Imprints (exemplars) were taken from 500 volunteers. The imprints were scanned as digital images, archived as read-only images and duplicated to create working files for each investigator.

Data was gathered and measurements recorded using two computer imaging programs. The information recorded consisted of data points involving the width of the incisors, the width of the dental arch, the degree of rotation of the incisors, the presence of diastemas (spaces), missing teeth, accidental damage and eventually will include the misalignment of each tooth in the arch (either, none, labio-version or linguo-version).

The findings provide the forensic Odontologist and the criminal justice system with the beginning of a valuable tool in providing statistical evidence for the objective statement of probability, in either exculpating or incriminating a suspect from patterned injuries caused by human teeth. It will also provide a means of developing a dental profile from a bitemark pattern when a suspect has not been identified, allowing investigators to concentrate their resources. Although DNA can be associated with a human bite, it cannot always be recovered as a means of linking a suspect to the bite.

Project Description

This project used an appropriate technique (empirical comparison) for examining several remarkable characteristics of the teeth, in a manner very similar to that used for the database generation of mitochondrial DNA (mtDNA).

Bradley Adams[1] suggests that "it is appropriate to compare the diversity of missing, filled and unrestored teeth with the diversity of mtDNA sequences formed by combinations of variants at multiple polymorphic sites within the mtDNA sequence." Adams, of course, is referring to decayed, missing and filled teeth. We feel that the same principle can be applied to such dental characteristics as arch width, tooth size, labio or linguo-version position in the arch, and degree of rotation of individual teeth. By adding spacing, accidental damage and missing teeth as additional data points, a sufficient number of specific remarkable characteristics will be archived to demonstrate individual statistical significance. Since a dental characteristic is not always a random event, like mtDNA sequences, each characteristic must be evaluated in relation to its frequency in the population. Some dental characteristics are more likely to occur than others. Rawson's study[2] considered all of the possible positions of each tooth occurring with random frequency. A database on the frequency distribution of commonly observed characteristics in the human dentition has to begin with an empirical study upon which to build. Like the database for mtDNA, it should be possible over several years to expand this study to establish a large database.

This sample size (n=400) was derived from power calculations by a biostatistician using nQuery Advisor ®. Final calculations have been accomplished using SAS® Statistical Analysis Software. The volunteer samples were randomly derived from dental clinic patients, representing a diverse population composed of Caucasian, Black, Asian and Hispanic males, age eighteen to forty-four that mirrors the population.

A total of five hundred thirty-one exemplars were registered, allowing for as many as 100 dropouts not meeting the quality necessary for the study. Four hundred nineteen of these Imprints (exemplars) were selected, scanned as digital images, archived as read-only images, duplicated as working files, data gathered and measurements recorded using two computer imaging

[1] Adams, BJ, The Diversity of Adult Dental Patterns in the United States and the Implications for Personal Identification, Journal of Forensic Science, May 2003, Vol. 48, No. 3

[2] Rawson, RD, Ommen, RK and Kinnard, JG, Statistical Evidence for the Individuality of the Human Dentition, Journal of Forensic Science, Jan 1984,Vol.29, No.1, pp 245-253

programs. The four hundred-nineteen acceptable exemplars were scanned utilizing an Epson Expression scanner®, model 1680, calibrated for accuracy and tested periodically for reliability by the imaging specialists assigned by the Wisconsin State Crime Laboratory. Adobe Photoshop CS2® and an automated software program under development at the University, dubbed Tom's Toolbox, were used in tandem as a means of quality control and the verification of the accuracy, reliability and validity of the automated program. The automated program recognizes ten, one pixel markers; each with a different green color value between 1 and 250. It was especially created for the project both as a means of quality control and as a more efficient means of making and recording large numbers of measurements.

Each digital image was opened within Photoshop®, the software, Tom's Toolbox, was imported with the ten points (pixels). According to the specific protocol, each of the points were dragged and dropped from the toolbox and inserted on the image at the areas to be measured. Each of the ten points has a specific unique RGB value. For the ten points, the red and blue values are 0; a unique green value is assigned to each point within the range 0 to 255. For example, the values for point 1 are (red: 0, blue: 0, green: 250), the values for point 2 are (red: 0, blue: 0, green: 235). After the ten points are inserted, the file is saved as a .TIF image.

Using Visual Foxpro with an ActiveX control for image manipulation, each .TIF image is processed. For each image, the program focuses on a region of the image where the bite impression exists in the image – rows 350 to 1250 and columns 50 to 1000. The program iterates through each pixel in the region and records the row and column coordinate for pixels which match the ten unique RGB values.

Once the ten points were identified, the computer performed two quality checks. The first quality check identifies missing points. In both the upper and lower jaw samples, the widths of the four incisor teeth are recorded, so two points should be identified for each of these teeth. If a tooth is missing in the subject, neither point should exist. If the tooth is present in the subject, both points should exist. The program reports a quality error as a missing point if one point is identified and the other point is not identified.

The second quality check ensures that the points are placed on the exemplar image in the correct sequence. For the lower jaw, points appear in sequence from left to right. For the upper jaw, points appear in sequence from right to left. The program evaluates the pixel columns for points 1 and 10 to validate sequence.

The program then performs calculations for width of teeth. The width is calculated using the Pythagorean Theorem. The equation for the jaw width is

$\sqrt{((|\ pixcol1 - pixcol2\ |)/118)^2 + ((|\ rowcol1 - rowcol2\ |)/118)^2}$ where pixcolx and rowcolx are the respective column and row coordinates for the two points of measure and 118 is the unit of measure in centimeters. Upon visual inspection of scale in multiple images, the scale of pixels was considered the same for rows and columns – one pixel is 1/118th of a centimeter. The equation for individual teeth width is $10\sqrt{((|\ pixcol1 - pixcol2\ |)/118)^2 + ((|\ rowcol1 - rowcol2\ |)/118)^2}$. The change in this formula is to convert the measurement from centimeters to millimeters.

Finally, the program performs calculations for the angle of the teeth. The equation for tooth angle is the arctangent of the opposite leg divided by the adjacent leg

$ARCTG((pixrow1 - pixrow2)/(pixcol1 - pixcol2))$

Following the same protocol and using the measure tool in Adobe Photoshop CS2®, a manual measurement was taken of the same characteristics. Information consisting of data points involving the width of the incisors, the width of the dental arch, the degree of rotation of the incisors, the presence of diastemas (spaces), missing teeth and the alignment or displacement of each tooth in the dental arch (that is, labio-version or linguo-version) were recorded. These measurements were than compared with the automated program measurements. This procedure not only verified the accuracy of the manual measurements; it also validated the reliability and accuracy of the automated software.

Descriptive statistics (mean, standard error) are reported for each characteristic, with the rotation angle characteristics stratified by rotation direction, (-) inward vs. (+) outward.

Since tooth position does not occur independently, a study was made of the correlation of jaw width and tooth width has on position. In order to describe associations between each of the measurements, pair-wise Pearson Product Moment correlations were computed. The estimated correlation and p-value for the null hypothesis of no association are reported in Figures 1 and 2. The pattern of correlation is stronger and more consistent in the mandibular arch. The maxillary arch, however, doesn't seem to follow a consistent correlation.

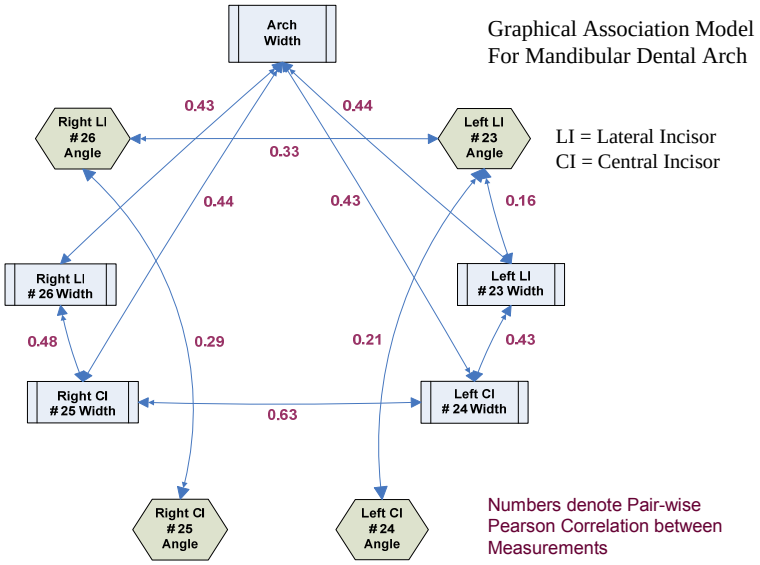

Figure 1. Graphical association model for the mandibular dental arch

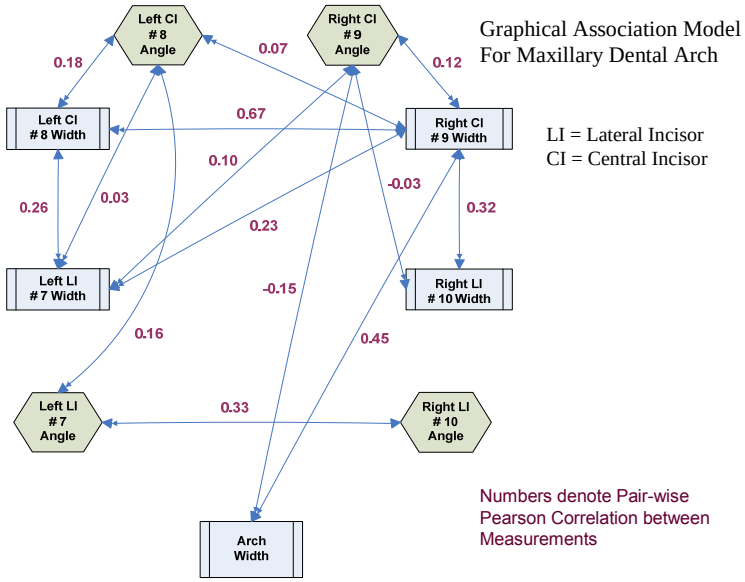

Figure 2. Graphical association model for the maxillary dental arch

For tooth rotations and widths, as well as for arch widths, the 1st, 5th, 95th, and 99th percentiles were used to classify the observed characteristic values as common, uncommon, or very

uncommon events, in a similar manner to Bernitz et al (2006)[3]. Results of arch and tooth widths are reported in Table 1.

Table 1. Classification of the widths of the dental arches and teeth.

Mandibular Arch	N	Very Uncommon Lower Width Values	Uncommon Lower Width Values	Common Width Values	Uncommon Upper Width Values	Very Uncommon Upper Width Values
Arch Width (cm)	415	≤ 2.26	> 2.26 to ≤ 2.37	> 2.37 to ≤ 2.96	> 2.96 to ≤ 3.11	> 3.11
Right Lateral Incisor # 26 (mm)	416	≤ 4.66	> 4.66 to ≤ 5.02	> 5.02 to ≤ 6.75	> 6.75 to ≤ 7.00	> 7.00
Right Central Incisor # 25 (mm)	419	≤ 4.33	> 4.33 to ≤ 4.58	> 4.58 to ≤ 6.20	> 6.20 to ≤ 6.63	> 6.63
Left Central Incisor # 24 (mm)	419	≤ 4.24	> 4.24 to ≤ 4.63	> 4.63 to ≤ 6.12	> 6.12 to ≤ 6.52	> 6.52
Left Lateral Incisor # 23 (mm)	416	≤ 4.40	> 4.40 to ≤ 5.09	> 5.09 to ≤ 6.82	> 6.82 to ≤ 7.14	>7.14
Maxillary Arch						
Arch Width (**cm**)	412	≤ 2.86	>2.86 to ≤ 3.00	> 3.00 to ≤ 3.66	>3.66 to ≤ 3.77	> 3.77
Right Lateral Incisor # 7 (mm)	416	≤ 3.46	> 3.46 to ≤ 4.59	> 4.59 to ≤ 7.44	> 7.44 to ≤ 7.73	> 7.73
Right Central Incisor # 8 (**mm**)	419	≤ 6.95	> 6.95 to ≤ 7.41	> 7.41 to ≤ 9.57	> 9.57 to ≤ 10.06	> 10.06
Left Central Incisor # 9 (**mm**)	418	≤ 6.66	> 6.66 to ≤ 7.38	> 7.38 to ≤ 9.49	> 9.49 to ≤ 9.91	> 9.91
Left Lateral Incisor # 10 (**mm**)	419	≤ 3.92	> 3.92 to ≤ 4.61	> 4.61 to ≤ 7.24	> 7.24 to ≤ 7.78	> 7.78

An alpha level of 0.05 was used throughout to denote statistical significance. All statistical analyses were performed using SAS v 9.1.3.

[3] Bernitz, H, van Heerden WFP, Solheim T, Owen J, A Technique to Capture, Analyze, and Quantify Anterior Teeth Rotations for Application in Court Cases Involving Tooth Marks. Journal of Forensic Science 2006, 51(3)624-628

Forensic Technology Need

The comparative forensic scientists are being challenged to provide a scientific basis for opinion testimony supporting a match between the known and unknown. Questions arise as to the probability of any two individuals in the population having the same characteristics. Research has begun to answer the challenge and the same technique developed for pattern analysis utilized in this research could eventually become the procedure in actual case work.

Technology Benefits

1. The study established statistical evidence that quantification of dental characteristics can be accomplished and that it is feasible to expand the study to begin a data base.

2. The development of this data set indicates that it is possible to support opinion testimony with statistical evidence.

3. An indirect benefit of the study was the development of an automated software program (Tom's Toolbox) to efficiently and rapidly measure the characteristics even more accurately than the tools available in Adobe Photoshop.

4. The protocol used in this study of dental characteristics has potential applications for analysis not only of bitemarks, but other pattern analysis in actual case work.

Collaboration

The Wisconsin Department of Justice, Crime Laboratory-Milwaukee provided two imaging specialists, who established the computer file hierarchy, calibrated and tested the hardware and software and provided a protocol for the continued validation of the accuracy of both. The crime laboratory personnel also provided assistance and assurance that our protocol followed the guidelines of the Scientific Working Group on Imaging Technology (SWGIT).

Factors concerning the admissibility of digital imaging and our statistical findings were monitored by the collaboration of a Professor of Evidence from the University Law School and technical support was provided by the University Information Technology Director, who provided soft-

ware programming and secured the necessary space for the archiving and back-up of our data on the Marquette University server.

Dissemination / Discussion

Statistical calculations are completed on all six characteristics. Statistical calculations also have been accomplished on a determination of intra-observer and inter-observer consistency. An example of observer agreement on the occurrence of outliers in the sample is illustrated in Table 2.

Table 2. Proportion of exemplars with outlying measurements in mandibular jaw

Collector	**Radmer**	**Johnson**
Number of Exemplars	416	410
Number of Outlying Traits	n (%)	n (%)
0	205 (49.3)	204 (49.8)
1	109 (26.2)	102 (24.9)
2	61 (14.7)	61 (14.9)
3	22 (5.3)	23 (5.6)
4	9 (2.2)	13 (3.2)
5	8 (1.9)	7 (1.7)
6	2 (0.5)	0 (0.0)

- Measurements were considered to be an outlier if they fell below the 5^{th} percentile or above the 95^{th} percentile of the observed sample distribution.
Characteristics used: arch width, tooth width and rotation for # 23, # 24, # 25, and # 26 incisors.

The first dissemination, entitled ***Quantification of the Individual Characteristics of the Human Dentition*****,** detailing the concept and need for the research was given at the February 2006 Educational Conference of the American Academy of Forensic Sciences. The following year, at the 2007 Educational Conference of the American Academy of Forensic Sciences, a presentation entitled ***Dental Science Assists Criminal Justice*** was given on the statistical trends developed during the first year of the research. Dissemination of the research methodology and the trend in data was accomplished by a paper entitled ***Dental Science Assists Criminal Justice: Methodology*****,** presented on July 23, 2007 at the International Association for Identification (IAI) annual educational conference in San Diego, California. A paper on the research methodology has been accepted for publication in the ***Journal of Forensic Identification*** (IAI) and an abstract has been accepted for a presentation on the completed research, entitled ***The Verdict is in: Can Dental Characteristics be Quantified?,*** at the annual educational conference of the American Acad-

emy of Forensic Sciences (AAFS) in February 2008 at Washington, DC. Following that conference, a paper on the completed research will be submitted for publication in the ***Journal of Forensic Sciences*** (JFS).